Space Weather Technical Forecast

Issued on Tuesday, 02 January 2024 at 13:24 Local

This technical forecast provides a four day assessment of space weather events. The probabilities stated below are for reaching or exceeding the given levels. For more information about space weather impacts please see the Met Office Space Weather Scales https://www.metoffice.gov.uk/weather/learn-about/space-weather/uk-scales

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Space Weather Forecast Headline: M-flares likely with a chance of isolated X-flares from AR3536. G1/Minor Storms likely day 1 (02 Jan) from glancing arrival of Dec 31 X5.0 CME.

Analysis of Space Weather Activity over past 24 hours

Solar Activity: Moderate with one M-flare observed, peaking at M4.7 at 01/1225 from AR3536. This remains the main region of note, with currently four numbered sunspots on the visible disc, and one newly unnumbered sunspot. Since the X5.0-flare on 31 Dec, some ongoing flux emergence has been apparent, however AR3536 has also been gradually rotating into a less oblique angle, with some of this apparent emergence likely due to this. The region is relatively small, but with a main spot of two opposite polarity umbrae with connected penumbra resulting in a delta-configuration. While still reduced from before the X5.0 flare, some rebuild of magnetic looping above the spot (e.g. in SDO aia-171) has also occurred through the last 24 hours. The other three spots are smaller, with AR3534 declining just west of the southern-centre disc, and the newly numbered AR3537 to the north of AR3536 is still showing signs of minor growth. During this period, we have seen a re-emergence of AR3535 in the southwest quadrant, which is difficult to analyse due its viewing angle, with this region due to rotate off disc soon.
No Earth-directed CMEs were observed in this period.

Solar Wind / Geomagnetic Activity: Solar winds perhaps showed a weak transient or more likely the onset of a CIR (co-rotating interactive region) ahead CH86/- fast winds. Background wind speeds persisted, but with a very gradual and step-wise increasing trend, rising from 330 km/s to around 450km/s by the end of the period. Density has been around average or slightly above throughout the period. Interplanetary Magnetic Field (IMF), Bt, has been mostly Moderate with a peak of 12nT. The north-south component, Bz, has been erratic in its strength throughout the period, reaching a minimum of -11nT at 01/2058 UTC, but has since been mostly weakly positive since 02/0130 UTC. Phi angle was generally negative (towards the Sun) but with occasional positive spells (away from the Sun). Geomagnetic activity increased from Quiet (Kp 0-2) to be Unsettled to Active between 01/1500-02/0300 UTC (Kp3-4).

Energetic Particles / Solar Radiation: GOES16 high energy (greater than 10MeV) proton flux was mostly at background, though a minor response post X5.0 flare was observed and is ongoing, with a rising trend from 01/2300 UTC to peak 4.6pfu at 02/0030 UTC. GOES16 high energy (greater than 2MeV) electron flux ranged was mainly at background. The 24-hour fluence was below Active throughout. The 02/0000 UTC observation was 2.67e6 integrated pfu.

Four-Day Space Weather Forecast Summary

Solar Activity: Region AR3536 in the northeast dominates the flare risk during the forecast period. Generally Moderate activity is expected, with further M-flares likely and a chance of further X-flares.

Solar Wind / Geomagnetic Activity: Fast X5.0 flare CME now dominates the solar wind forecast. This has been assessed as passing largely behind Earth, however an impact is

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possible predominately from its shock, which at the time of writing has still not materialised. This will likely increase solar wind speeds, perhaps to Elevated or Strong levels (600-750km/s), but with the ejecta largely missing, only a relatively limited geomagnetic response is currently expected. Confidence is low however, due to the source of the CME being close to the east limb.

Otherwise, Earth is currently in a weak fast wind from CH86/-, which should gradually ease through the period.

Geomagnetic activity is currently mostly Quiet, with a chance of Unsettled or Active intervals with the fast wind. However, any CME arrival could bring a chance of Active to G1 Minor Storm intervals and a slight chance of G2 Moderate Storms day 1 (02 Jan). There remains a chance of Active and a slight chance G1 Minor Storm intervals into day 2 (03 Jan), but otherwise geomagnetic activity easing back towards mainly Quiet with Unsettled intervals from day 3 (04 Jan).

Energetic Particles / Solar Radiation: GOES16 high energy proton flux is expected to remain below S1 storm levels, however there remains a slight chance of breaching the S1 threshold into the period, initially as the CME arrival occurs, and then later in the period should any further notable flares occur. GOES16 high energy electron flux is likely to remain near background in the short term, but is expected to reach Moderate levels, with a chance of reaching High from day 3 (04 Jan). The associated 24 hour fluence is expected to remain below Active through the period, but with a rising trend by the end of the period in response to the CME and fast wind arrivals.

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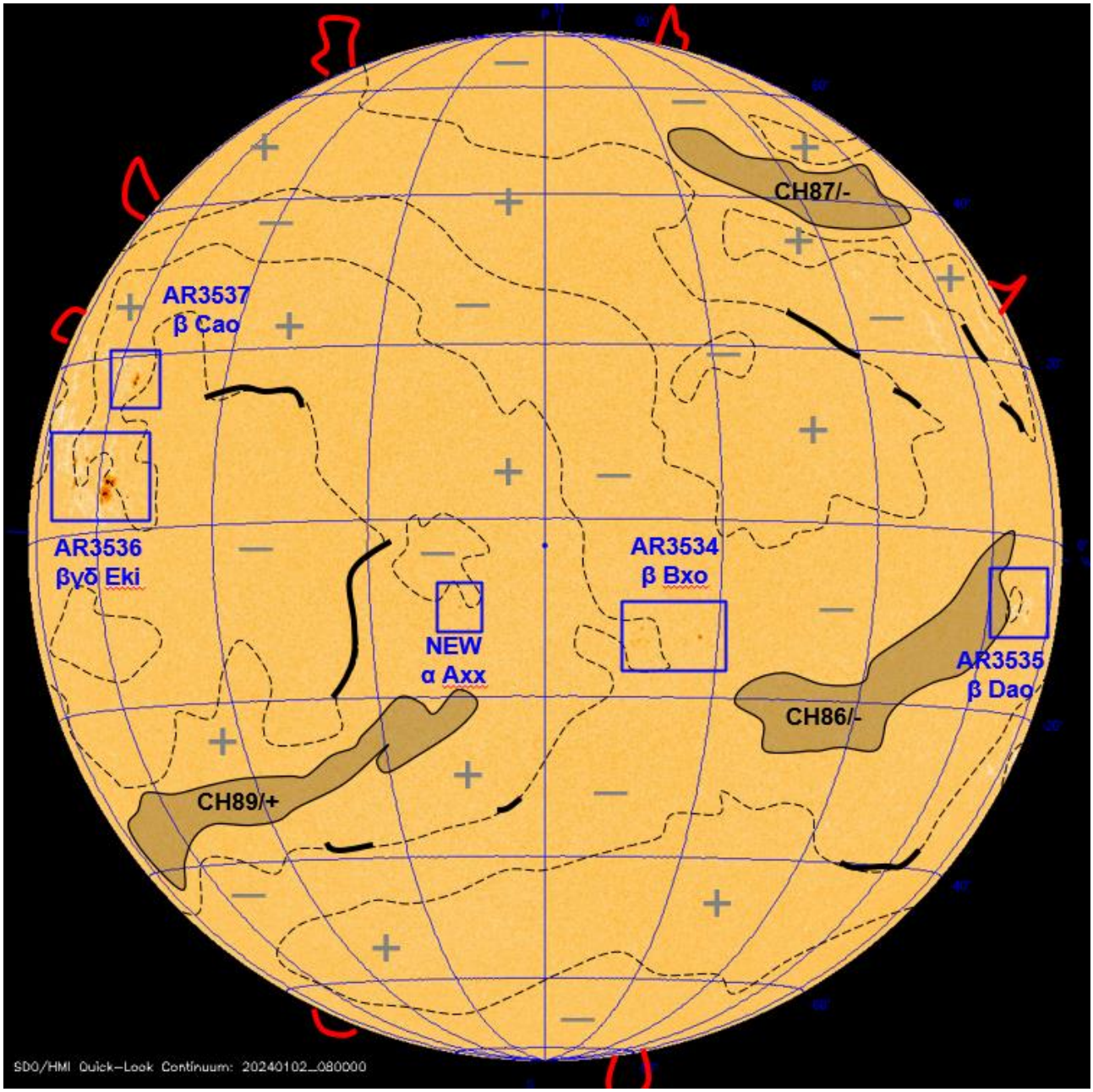
Figure 1. Solar Analysis Valid 02/0800UTC.



Key: Filament ___ , Prominence ___ , Magnetic Field Line - - - , Polarity +/-, Coronal Holes: Grey shaded area CHxx +/-, Sunspot groups 25xx - Mt Wilson α-β-βγ-βγδ and Zurich-McIntosh Axx etc.

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Geomagnetic Storms:

The most notable recent CME with the potential for Earth-directed components was the fast CME from the X5.0 flare near the east limb. This was a complex eruption with a fast central portion and broader, wide shock. Furthermore analysis of this CME is complicated by a lack of STEREO A imagery, reducing confidence in assessing the potential for an Earth-directed component. However, the current assessment is for Earth to most likely see a glancing and shock based impact around 02/1200 UTC +/- 9hours. This may bring a period of elevated to strong wind speeds (600-700 km/s).

There are a number of other CMEs which were considered for possible very slight glancing impacts. This includes CMEs from filament eruptions on 30 and 31 Dec, a C-flare CME on 30 Dec and a corona sourced CME also on 30 Dec, with arrivals on 02 Jan and late 03 or early 04 Jan. Due to the weak, and likely imperceptible nature of any of these arrivals, especially over the above CME, these have now been removed from the subsequent forecast but this may need to be reconsidered if the above arrival does not occur.

Earth is currently in a high speed stream from CH86/- with Slightly Elevated speeds, currently near 420km/s. Elevated to Strong winds are then likely from any shock/CME arrival, with these expected to gradually ease later day 2 (03 Jan) onward.

Geomagnetic activity is currently Quiet and is forecast to become Unsettled to Active due to the fast wind from CH86/- during day 1 (02 Jan). Any CME arrival will bring a chance of Active to G1 Minor Storm intervals and a slight chance of G2 Moderate Storms during day 1 (02 Jan). There remains a chance of Active and a slight chance G1 minor storm intervals into day 2 (03 Jan), but otherwise geomagnetic activity easing back towards mainly Quiet with Unsettled intervals from day 3 (04 Jan).

Geo-Magnetic Storm Probability (Exceedance)	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Minor or Moderate	G1 to G2	No	60	20	5	1
Strong	G3	No	1	1	1	1
Severe	G4	No	1	1	1	1
Extreme	G5	No	1	1	1	1

Geomagnetic Activity - Earthbound Coronal Mass Ejections

Date/time 21.5R (UTC)	Halo: Full or Partial	Source	Source Location	Estimated Speed	Estimated Arrival Time	Comments
23/0025	Partial	X5.0 AR3536	NE limb	1500km/s	02/1200 +/- 9hrs	Low confidence. Glancing blow or shock

Figure 2: MOSWOC Enlil and ensemble, dominated by CME arrival during 02 Jan.

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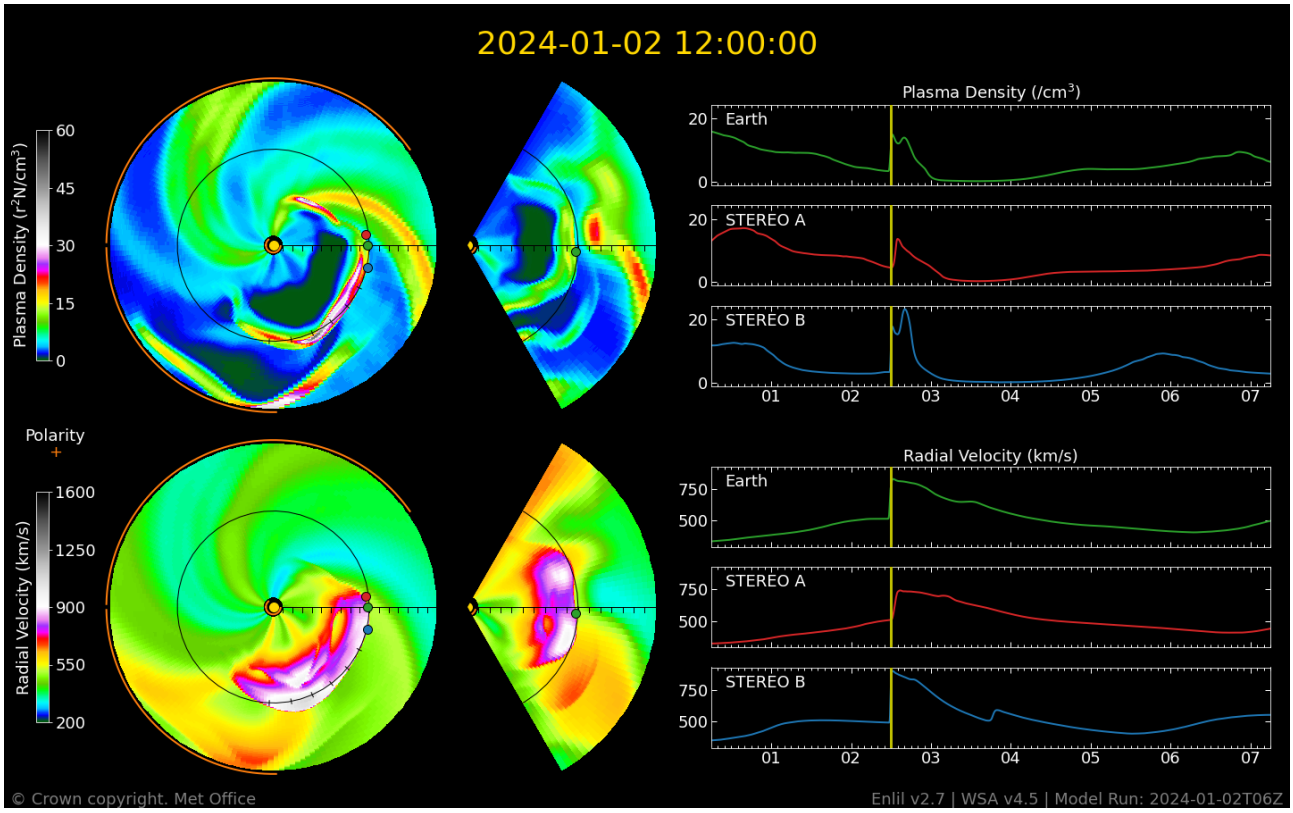
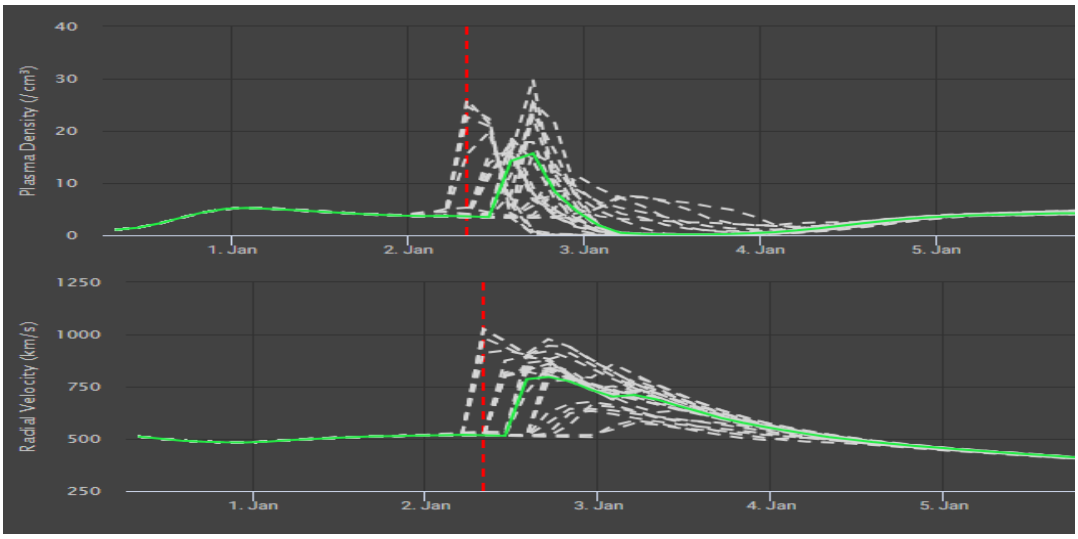
Space Weather Technical Forecast





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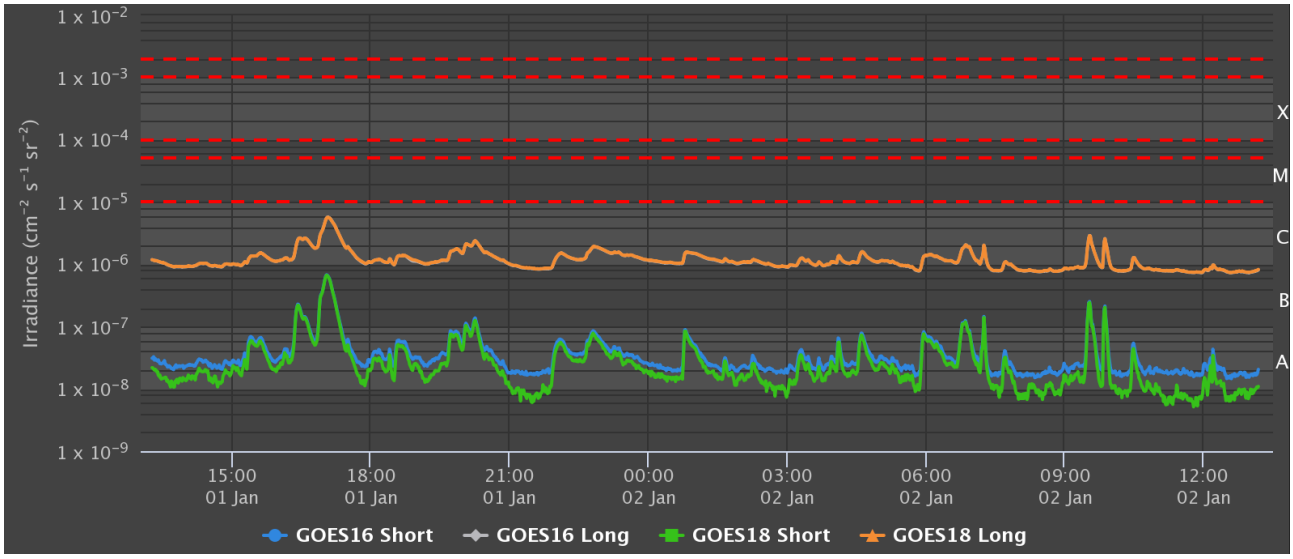
Radio Blackouts - X-Ray Flares:
Moderate activity is likely to continue, with M-flares and a chance of isolated X-flares from AR3536.

This remains a relatively small region set with a broad area of plage, with a main spot consisting of opposite polarity spots within a connected penumbral area, resulting in a delta-configuration. The main spot has a number of smaller spots around it of different polarities, with either ongoing emergence or increased visibility due to decreasing viewing angle suggesting some growth. Furthermore, magnetic looping in the canopy above the spot appears to be rebuilding (e.g. in aia-171) although still remains simpler than was apparent before the X5-flare. Given the history of strong flares, and an apparent rebuilding trend, further activity is expected from this spot.

There are three other numbered regions on the visible disc. This includes a small, decaying region just west of the centre southern disc, and AR3537 which rapidly developed to the north of AR3536. These are a lower risk for flares, however any further growth from the new region will also bring the potential for M-flares. AR3535 has re-emerged in the southwest quadrant, although this is now difficult to analyse due to its viewing angle.

X Ray Flares Probability	Level	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	R1-R2 M Class	Yes	60	60	60	60
Very Active	R3 to R5 X Class	No	25	25	25	25

Figure 3: GOES-16 X ray flares.



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Solar Radiation Storms - (High Energy Protons):
GOES16 high energy (greater than 10MeV) proton flux showed a modest response to the 31 Dec X5.0 flare from AR3536 on the east limb, but has remained well below the S1 Minor Storm level. Further flares have the potential to increase this flux, with a slight chance of rising above, especially as this regions continues to rotate west across the disc. A potential brief increase is also possible ahead of and with any shock/CME arrival on day 1 (02 Jan).

Radiation Storms Probability (Exceedance)	Level (cm^{-2} sr^{-1} s^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC) (%)	Day 2 (00-24 UTC) (%)	Day 3 (00-24 UTC) (%)	Day 4 (00-24 UTC) (%)
Active	**≥ S1**	No	20	10	10	15
Very Active	**≥ S3 ***	No	1	1	1	1

* S3 ≥ 10 MeV ≥ 1000 pfu and / or ≥ 50 MeV ≥ 10 pfu. (pfu = $cm^{-2}sr^{-1}s^{-1}$)

Figure 4: GOES-16 proton flux

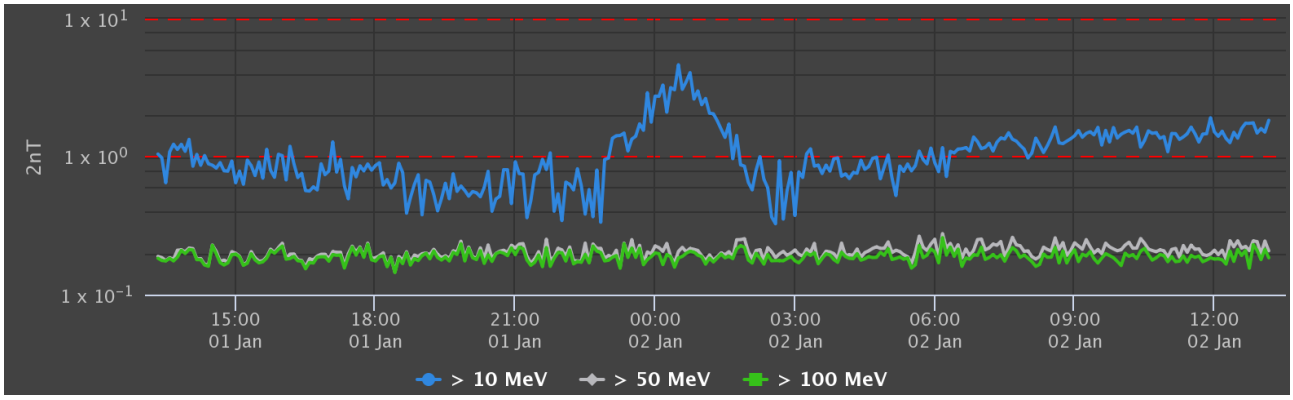
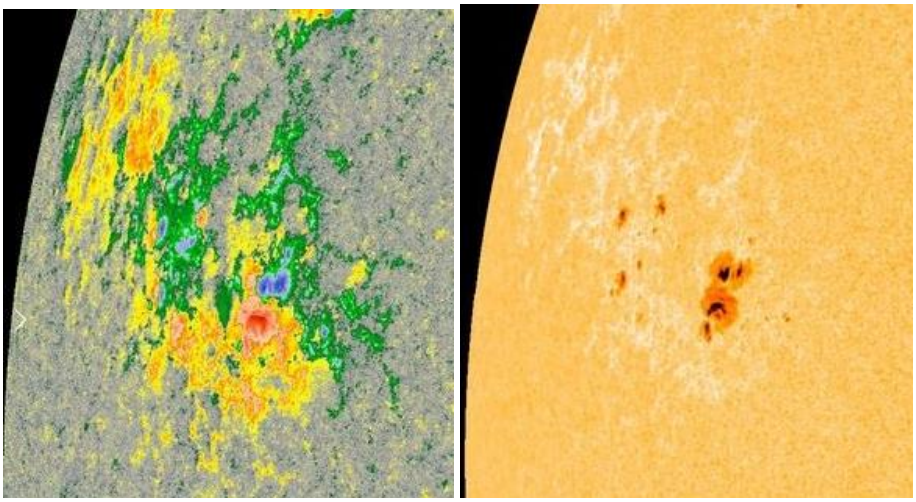


Figure 5: SDO intensitygram and magnetogram showing AR3536 in the northeast.



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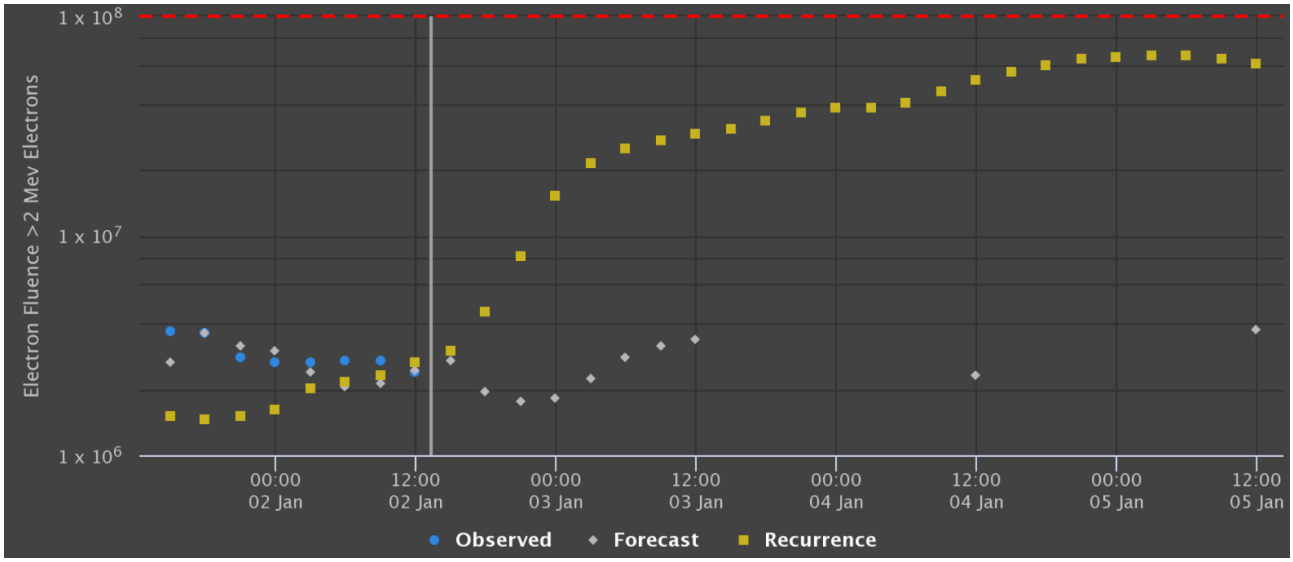
High Energy Electrons Event (≥ 2MeV):
High energy electron flux (greater than 2MeV) as observed by GOES-16 continues to persist at mostly background levels. The onset of fast winds, followed by the likely CME arrival on day 1 (02 Jan) will lead to a disturbed geospace environment but also a subsequent potential charging of the compressed Van Allen Belts. As these ease back to GEO, there is the potential for observed flux to increase to Moderate, perhaps High, although this is low confidence as this depends on the enhancement from any CME arrival.

Electron fluence is expected to remain below the Active (1e8 integrated pfu) threshold, but likely with a gradually increasing trend from day 2 (03 Jan). REFM is currently giving good guidance in the absence of any fast wind or CME arrival, however once this occurs, this guidance will become less useful.

GEO Electron Environment	Level (cm^{-2} sr^{-1} day^{-1})	Past 24 Hours (Yes/No)	Day 1 (00-24 UTC)	Day 2 (00-24 UTC)	Day 3 (00-24 UTC)	Day 4 (00-24 UTC)
Probability (Exceedance)			(%)	(%)	(%)	(%)
Active	≥ 2 MeV ≥ $1x10^8$	No	1	5	20	25
Very Active	≥ 2 MeV ≥ $1x10^9$	No	1	1	1	1

Figure 6: MOSWOC REFM electron fluence, observations and forecast.



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